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MODEL EXPERIMENTS ON THE ACOUSTIC SIGNAL FROM AIR-DROPPED MINES II (MK 39 and RIA)

Final Report on

Contract Nonr-1287 (00)

November 30, 1953

Catholic University of America

Washington, D. C.

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MODEL EXPERIMENTS ON THE ACOUSTIC SIGNAL FROM AIR-DROPPED MINES II.

(MK 39 and RIA)

by

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INTRODUCTION

Air dropped mine cases often give more than one distinct acoustic signal. Experiments using a model of the Mark 36 mine have been performed and show that most of these signals can be accounted for. They are due to water entry, parachute rim tearing the cavity wall, and broadside slap of the mine case against the cavity wall. (Model Experiments on the Acoustic Signal from Airdropped Mines - Nonr contract 894-00 Dec. 31, 1952). This paper is a continuation of the above cited reference using models of the Mark 39 mine and the RIA Russian mine. Simultaneous high speed motion pictures of the water entry of the projectiles and their subsequent behaviour were taken together with acoustic records.

The experiments were performed at N.O.L. where the tank, the air gun, and the photographic equipment used by McMillen and May in their photographic water entry studies were put at our disposal.

EQUIPMENT

The experimental arrangement was essentially the same as that described in the previous report. This description will not be repeated, but only the few changes enumerated.

The motion picture camera, a 16 mm high speed Eastman Kodak type 3 was modified so that it gave not only the optical record of the motion of the model as previously, but that it recorded simultaneously the trace of one of the two oscilloscopes. An F-2, 63 mm focus lens was used for the latter purpose and an F-1.9, 25 mm focus lens was used for the movies. The speed was about 1800 frames per second.

A lucite rod placed near the hydrophone had three-inch spacings marked on it. The rod and clock (see previous report) appearing on each frame provide a means for determining the speed of the projectile.

The two oscilloscopes were both Dumont 304 H and were both used in parallel in all shots; the trace of one was photographed by the movie camera, that of the other by a Polaroid camera.

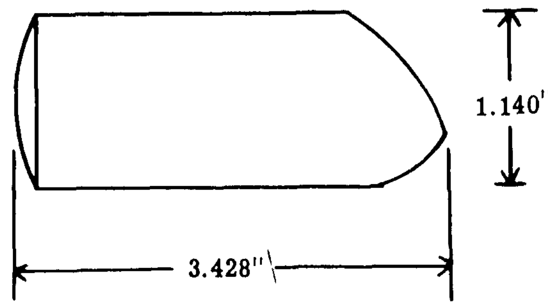
To photograph the sound signal from a tapped model, in which case a fast sweep (5-10 msec) was used, the Polaroid camera was replaced by a camera having an F-2, 50 mm focus lens.

The pulse delay was omitted.

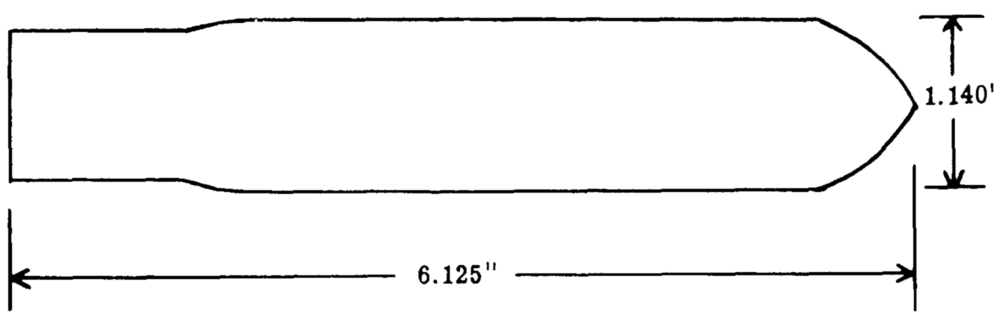
The pressure in the air gun was generally kept at 90 psi but for some slower speed shots pressures of 75 and 50 psi were used.

PROJECTILES

The models studied are shown in Figure 1. The scale factor of the Mark 39 was 1/19.58 and of the RIA was 1/18.42. The only information available on the RIA gave the dimensions and weight but not the center of gravity or the moment of inertia about a transverse axis. Because of this the model case was threaded on the inside and contained two threaded plugs which could be moved to change the center of gravity. Three different positions of the center of gravity were used: (1) position F which was forward from the tail of the mine by 60.0% of the total length, (2) position M which was forward by 55.5% of the length, and (3) position R which was forward by 46.8% of the length.



Mark 39 Scale factor 1/18.42



RIA Scale factor 1/18.42

Figure 1

The ogive nose of the Mark 39 causes the mine to experience on water entry hydrodynamic forces which make it rotate and slap against the cavity wall. The side of the mine opposite the nose is the side that slaps. For the sake of simplicity, geographical designations will be used to describe positions relative to the hydrophone, according to the sketch below.

N

W x E

S

hydrophone

In all cases the projectiles struck the water surface at a point (x) north of the hydrophone. The model of the Mark 39 was placed in the sabot with the nose oriented in different directions so as to gain information on the directivity of the slap signal. With the nose north the mine case slapped against the south side of the cavity near the hydrophone.

PROCEDURE

The sequence of events for firing a projectile was the same as described in the previous report. The pulse from the bottom photocell was fed into an amplifier and then into the external synchronization terminals of the two oscilloscopes. The x-axis on each oscilloscope was spread out until the desired sweep speed was obtained and moved left or right until the acoustic signals appeared on the trace. This method allowed for the time it takes the projectile to travel from the bottom photocell to the water surface, thus eliminating the pulse delay unit.

Some experiments were performed to measure the frequency of the water entry signal and vibrations of the mine case. For these a fast sweep was used. The oscilloscope was set to trigger on entry or in the cases of tapping the mine case to trigger on the first signal received.

In all cases a calibrating trace from a Hewlett Packard audio oscillator was photographed in order to have a sine wave of known frequency for measuring the times the signals occurred after entry.

With the exception of the experiments using a fast sweep all data were taken with the same oscilloscope setting which allows a comparison of signal amplitudes.

RESULTS

Underwater Behavior of Models and Cavities

The Mark 39 always turns after water impact and slaps broadside against the cavity wall on the side opposite from the point on its ogive nose. The time interval between initial water entry and this broadside slap varies with the angle of initial entry as shown in Graph I. As would be expected this time interval is also increased when the velocity of the projectile is decreased. After slapping the cavity wall this model continues to turn until it is descending with the tail downward as shown in earlier model studies of the underwater path. (NOLM No. 7449, 29 June 1945)

The behavior of the RIA model under water is quite erratic. The following types of motion were observed on films:

(a) The model on vertical entry may travel straight down without any slap against the cavity wall, the cavity appearing similar to that of a sphere.

(b) The model may turn and slap against the cavity wall. The time and amplitude of this slap shows wide variations.

(c) The model may slide along its cavity wall with no pronounced slap. This type of entry is very common when the entry is removed from the vertical.

The cavity formed in the water by the entering model first closes at the water surface. In no case was any sound detected from this.

The cavity formed by the Mark 39 separates into two parts about 10 milliseconds after the surface closure. The upper part separates from the lower at about the point where the rear edge of the model begins to tear the cavity wall. This upper section of the cavity then closes rapidly and in most instances a small sound signal is recorded at the time of this closure.

The sound records on the Polaroid camera show a distinct entry noise. This is followed at 1-2 millisecond intervals by much smaller signals. In the previous report these were listed but are omitted now, since we consider them as the result of shock excitation of the model by the entry. This is followed by a second signal 5-10 milliseconds later; this time interval agrees very well with the time of the slap as taken from the movie film. Occasionally these is followed by an unexplained signal appearing about 12 milliseconds after entry. For the Mark 39 there comes next a signal which coincides in time closely with the closure phenomenon described above. The data are shown in Tables 1a and 1b. While the optically measured event and the acoustic signal agree to within 1 millisecond, the trace on the movie camera shows that in reality this agreement is within one frame, i.e., within 0.5 milliseconds.

Oscillograph (Polaroid Land camera) data and high speed movie film data. Slap and underwater cavity closure times are in milliseconds after initial impact. Trajectory vertical. Model turned during air flight and struck the water at some angle θ measured from the vertical. R and L indicate right and left of the vertical as measured on the movie film.

Table 1a - Mark 39

Shot Number	Nose Azimuth	θ	Entry Velocity ft/sec	Slap		Underwater Cavity Closure*	
				Acoustical	Optical	Acoustical	Optical
22J9B	N	2R	97	6.0	5.0	20.0	--
22J9C	N	3R	99	6.0	6.5	21.0	20.5
22J9D	N	2R	116	6.0	6.0	20.0	20.0
23J2B	N	1R	103	6.0	5.5	22.0	--
23J2C	N	4R	103	6.0	5.5	18.0	18.0
27J1B	N	0	100	7.0	6.3	20.0	20.0
27J1C	N	4L	105	8.0	7.3	20.0	20.5
27J2A	N	0	109	6.0	7.0	20.0	21.0
27J2B	N	5L	106	8.0	7.7	18.0	20-22
27J2C	N	5L	105	7.0	8.0	20.0	21.3
27J2D	N	5R	100	5.0	5.0	19.0	19.5
27J2E	N	3R	94	6.0	6.5	22.0	20-22
29J1B	N	3R	109	5.0	5.7	20.0	--
29J3A	N	3L	104	7.0	7.3	21.0	--
29J2B	N	7L	75	12.0	12.7	28.0	29-30
29J2C	N	0	75	9.0	10.0	25.0	--
28J2B	W	0	96	--	8.0	20.0	20.5
28J2C	W	4R	91	8.0	8.8	25.0	21.0
28J1A	E	3R	94	7.0	6.2	--	--
28J2A	E	3R	91	5.0	5.6	19.0	18.5
28J3A	S	2L	93	--	--	18.0	18.4
28J3B	S	0	91	--	--	18.0	18.8

*It is interesting that the times recorded for deep closure 19-22 m sec., agree closely with those found by A. May, Jour. Appl. Phys. 23, 1362, 1952, for steel spheres of 1/2-inch diameter. One hundred ft. per second corresponds to 1.2 inches per m sec.; the diameter of the model is 1 inch, therefore our experiments correspond to the abscissa 0.8 in May's Figure 11. At 1 atm. the corresponding time given by May's curve is 19 m sec.

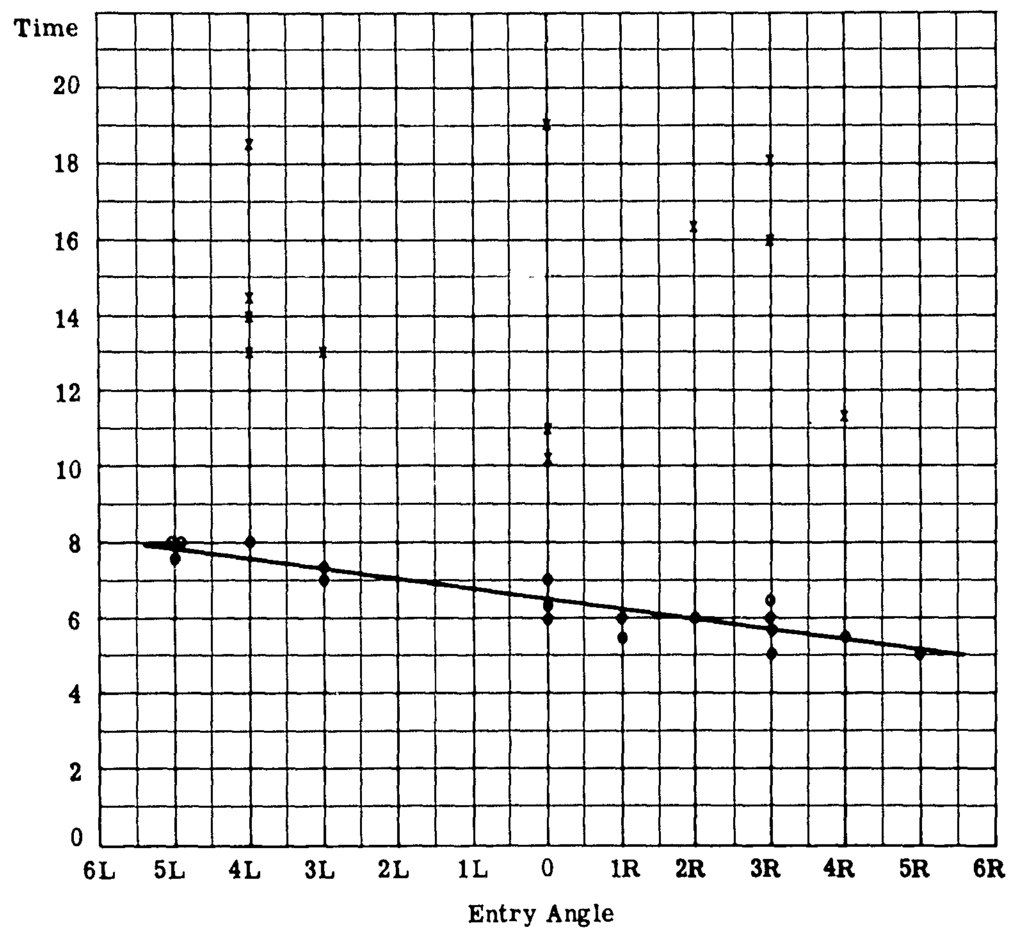
Table 1b - RIA

Shot Number	θ	Entry Velocity ft/sec	Position of Center of Gravity	Slap	
				Acoustical	Optical
30J7A	4L	65	M	--	14.5
30J7B	3L	71	M	13.0	--
30J7C	6L	72	M	--	--
4A2A	3R	74	M	--	--
4A2B	3R	69	M	18.0	18.2
4A2C	4R	70	M	12.0	11.3
4A3A	10L	74	M	--	--
4A3B	4L	74	M	13.0	13.2
4A3C	2R	51	M	--	16.5
4A3D	0	54	M	19.0	--
4A4A	4L	67	F	14.0	--
4A4B	2L	67	F	--	--
4A4C	6L	66	F	--	--
5A1B	4L	45	F	--	18.7
5A1C	3R	52	F	16.0	15.5
5A2A	0	90	R	12.0	11.0
5A2B	0	74	R	--	10.3
5A2C	4R	50	R	--	--
5A2D	0	49	R	--	--

GRAPH 1

Time slap occurred after water entry in milliseconds
vs.
Angle of entry in degrees measured from the vertical
(Photographic record)

x RIA Model
o Mark 39 Model



The signal which coincides with the underwater closure of the cavity appears to be a composite of many frequencies. In so far as could be obtained from the oscilloscope traces on film a frequency of about 55 kilocycles per second appeared to be present. In no case was this closure signal detected when the hydrophone was as much as 20 inches from the point of entry. No variation in intensity of this sound with azimuth was observed.

In the RIA shots signals which might be attributed to cavity closure were observed in only a small percentage of cases and in these cases they were very weak.

Effect of Entry Velocity

In order to study the effect of entry velocity on the acoustic signals, shots were fired with the gun pressure reduced to 50 psi. This pressure produced average velocities of 75 ft/sec for the Mark 39 and 50 ft/sec for the RIA. These data are summarized in Table 2 and indicate:

(a) The time interval between initial entry and slap increases in about the same proportion as the decrease in velocity. The time interval between initial entry and cavity closure also increases with decreasing velocity but by a smaller amount.

(b) The amplitude of all acoustic signals decreases with decreases in velocity, but the decrease in the slap noise is less than that for initial splash.

(c) No changes are observed in the frequencies excited when the velocity is changed.

Table 2

Acoustic Signals under Different Entry Velocities

Model	Velocity ft/sec	Entry Signal Amplitude	Slap Signal Amplitude	Closure Signal Amplitude	Slap Time (m sec)	Closure Time (m sec)
Mk39	104	2.6	4.4	1.1	6.3	20.1
Mk39	75	1.1	3.1	0.5	9.8	26.1
RIA	72	2.3	1.7	--	14.0	--
RIA	50	0.9	0.5	--	17.5	--

Effect of Changing the Center of Gravity of the RIA

Table 3 summarizes the effect of changing the center of gravity of the RIA. The position of the center of gravity appears to have no effect on the initial entry signal or on the likelihood of slap occurring. As the center of gravity is moved aft the time interval before slap occurs decreases and the amplitude of the slap signal increases.

Table 3

Center of Gravity Position	No. of Shots	Entry Signal Amplitude	No. of Slaps Observed	Average Time of Slap after Entry (m sec)	Average Amplitude of Slap
F	4	2.8	2	15.0	1.0
M	15	2.2	7	12.7	1.9
R	2	2.5	1	12.0	3.5

Angle of Trajectory

A series of shots were made with the gun placed so that the model entered the water along a trajectory inclined at 11 degrees south of the vertical. These results are compared with vertical entry in Table 4. The data from these shots indicate:

(a) When the Mark 39 enters the water at an angle with the point of the ogive nose up, there is a large entry signal which persists until slap occurs.

(b) When the Mark 39 enters the water at an angle with the point of the ogive nose down, the entry signal is small. No slap was heard in these cases with the hydrophone located on the opposite side of the cavity.

(c) The RIA shows slightly greater entry signal when entry is along a non-vertical trajectory.

(d) Closure signals are not noticeably affected by angle entry.

(e) No change in frequencies excited was observed on change of the entry angle.

Table 4

Comparison of Acoustic Signals for Vertical and Nonvertical Trajectories

Model	Trajectory Angle	Nose Orien-tation	Entry Signal Amplitude	Slap Signal Amplitude	Closure Signal Amplitude	Slap Time (m sec)	Closure Time (m sec)
Mk39	0	North	2.6	4.4	1.1	6.3	20.1
Mk39	0	South	2.7	0	1.0	--	20.0
Mk39	11°	North	5.3	3.1	1.0	7.6	24.6
Mk39	11°	South	2.2	0	1.0	--	25.8
RIA	0	--	2.3	1.7	--	14.0	--
RIA	11°	--	2.7	0	--	--	--

Direction of Propagation of the Acoustic Signals

In order to study the direction of propagation of the sounds made by the models, shots were fired with the hydrophone in eight different positions. Relative amplitudes of the sounds were determined by comparing the heights of the signals on the oscilloscope. The results are tabulated in Tables 5a and 5b and indicate:

(a) The signal from initial entry shows no preferred azimuth, but travels downward rather than horizontally.

(b) The signal from slap of the model against the cavity wall is quite directional. This shows large amplitude on the side where slap occurs while little or no signal is observed on the side opposite the slap.

It is believed that the acoustic image in the surface plays an important part in these directional effects but no details have been worked out.

Table 5A

Relative Signal Amplitude at Different Hydrophone Positions for Mk39

Hydrophone Position		Nose Orientation	Entry Signal Amplitude	Slap Signal Amplitude	Closure Signal Amplitude
Depth (in)	Lateral Distance from Entry (in)				
6	7	North	2.6	4.4	1.1
1	7	North	0.9	4.2	0.4
12	7	North	2.2	4.0	1.7
18	7	North	2.2	1.0	--
1	20	North	0.5	4.2	--
6	20	North	1.0	3.5	--
12	20	North	1.0	1.0	--
18	20	North	1.0	1.0	--
1	7	South	1.2	--	1.5
6	7	South	2.7	--	1.0
1	7	East	0.5	2.0	0.5
6	7	East	2.3	3.2	1.0
12	7	East	2.5	1.8	1.2
18	7	East	2.5	1.5	--
1	7	West	0.7	1.5	0.5
6	7	West	1.8	1.7	1.2
12	7	West	2.3	1.7	1.7

Table 5B

Relative Signal Amplitude at Different Hydrophone Positions for RIA (Only entry signals are tabulated since slap signals are erratic and closure signals seldom detected.)

Hydrophone Position		Entry Signal Amplitude
Depth (in)	Lateral Distance from Entry (in)	
1	7	2.1
6	7	2.1
12	7	2.6
18	7	2.0
1	20	1.0
6	20	1.8
12	20	1.8
18	20	2.2

Frequency Analysis of Acoustic Signals

An attempt was made to read the frequencies from the oscilloscope trace on the high speed movie film. This was done by putting a 20,000 cycle trace on one film and then comparing the other films to this in a comparator. This reading was difficult because of the complexity of the sound signals which appear to contain many high frequencies. Shots were also made with a fast oscilloscope trace which triggered on entry. In addition photographic records were made of the sound signals from tapping the models.

Results are summarized in Tables 6A and 6B. The (x) indicates that the frequency was observed in one or more instances and the (--) indicates that the frequency was not

Table 6A

Frequencies Observed from Mk39 Model

Frequency Kilocycles/sec	Number of Times Observed in				
	Entry Signal from Films	Entry Signal from Scope Triggered on Entry	Slap Signal from Films	Model Tapped on Nose	Model Tapped on Side
8	x	x	x	--	x
15	x	--	--	x	--
20	--	--	x	x	x
27	x	x	x	x	x
40	x	--	x	x	--
55	x	--	x	--	x
70	x	x	x	--	--
80	x	--	x	--	--

Table 6B

Frequencies Observed from RIA

Frequency Kilocycles/sec	Entry Signal from Films	Slap Signal from Films	Model Tapped on Nose	Model Tapped on Side
15	--	x	x	x
27	x	x	--	--
33	x	x	--	x
40	x	x	x	--
55	x	x	--	--

observed. These data seem to indicate that the sound signals made by the models in the water originate from vibrations in the models. However many higher modes of vibration, which are not excited on tapping, contribute to the under water sound signals.

A transducer was attached to a full size Mk 39 mine case and the case tapped with a hammer. The lowest frequencies detected were 2.0, 5.0, and 6.7 kilocycles per second which seemed to be reasonable compared to those found in the models.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the Armament Branch of ONR as the supporting agency for this work; to the director of the Naval Ordnance Laboratories who placed the facilities of the laboratory at our disposal, and in particular to Drs. G. Hartman and T. Johnston; to many at N.O.L. for timely assistance at every stage of the experimental work, especially to those in the photographic section; and to Dr. K. F. Herzfeld under whose guidance this work was done.

MARK 39 - VERTICAL TRAJECTORY

E - Entry
S - Slap - 7.0 milliseconds
UC - Underwater closure of cavity - 24 milliseconds
High frequency about 1500 cps

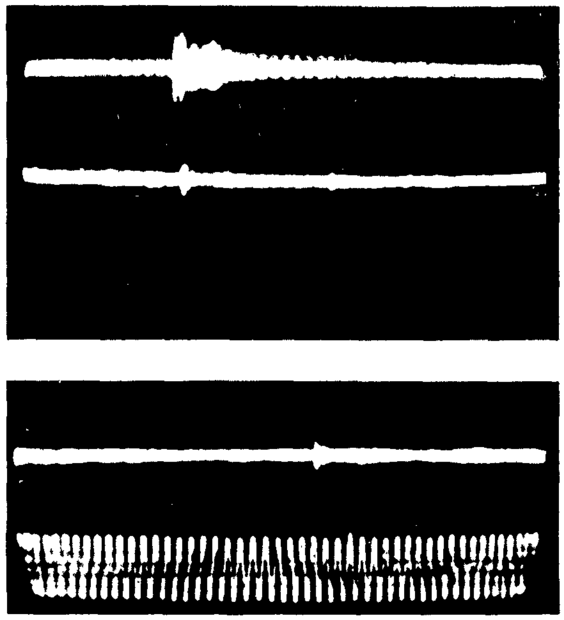
RIA - VERTICAL TRAJECTORY

A

B

C

D

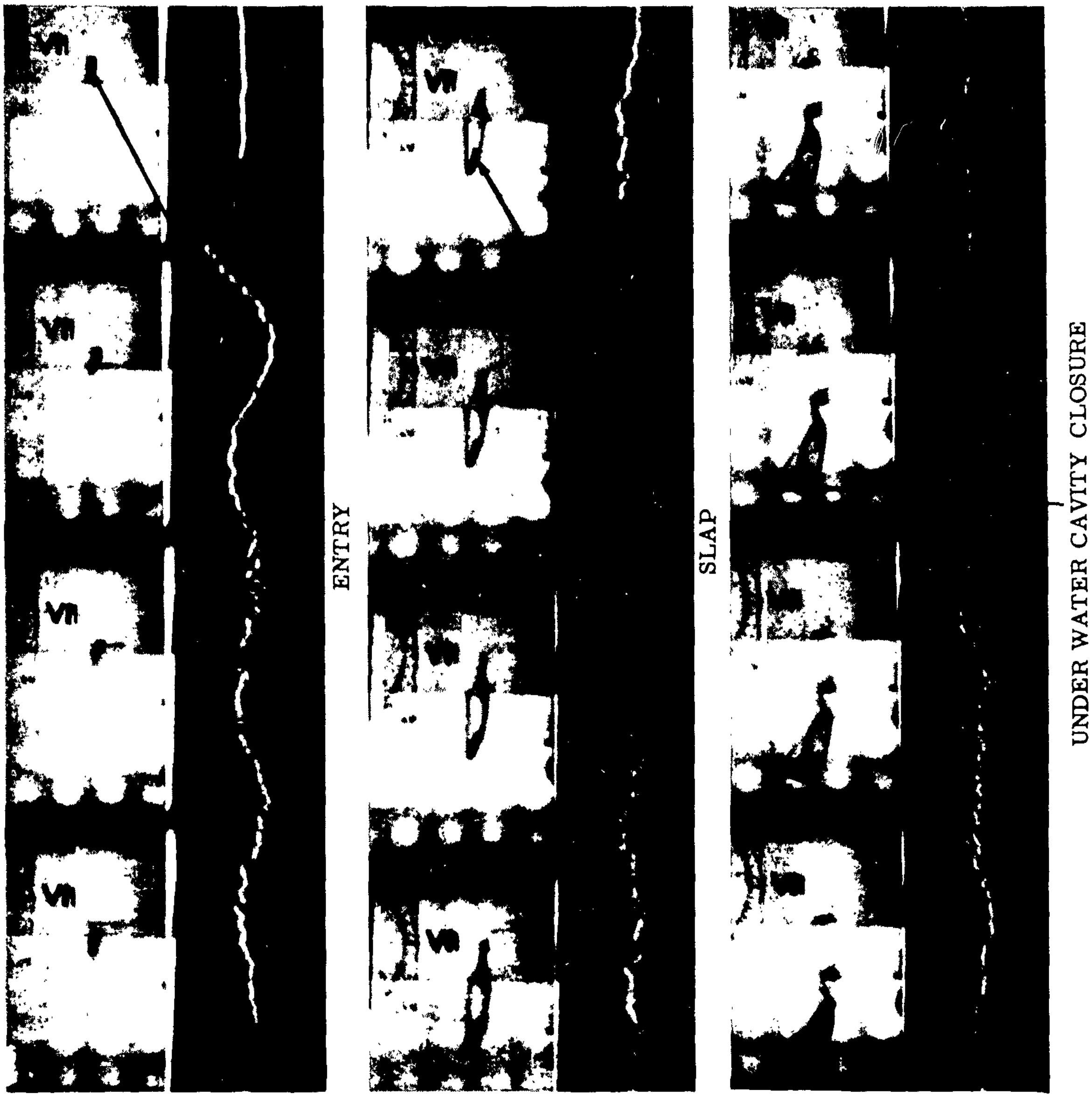


6A5 A - MARK 39 Trajectory 11° from vertical
nose up Slap 7.5 milliseconds

B - MARK 39 Trajectory 11° from vertical
nose down

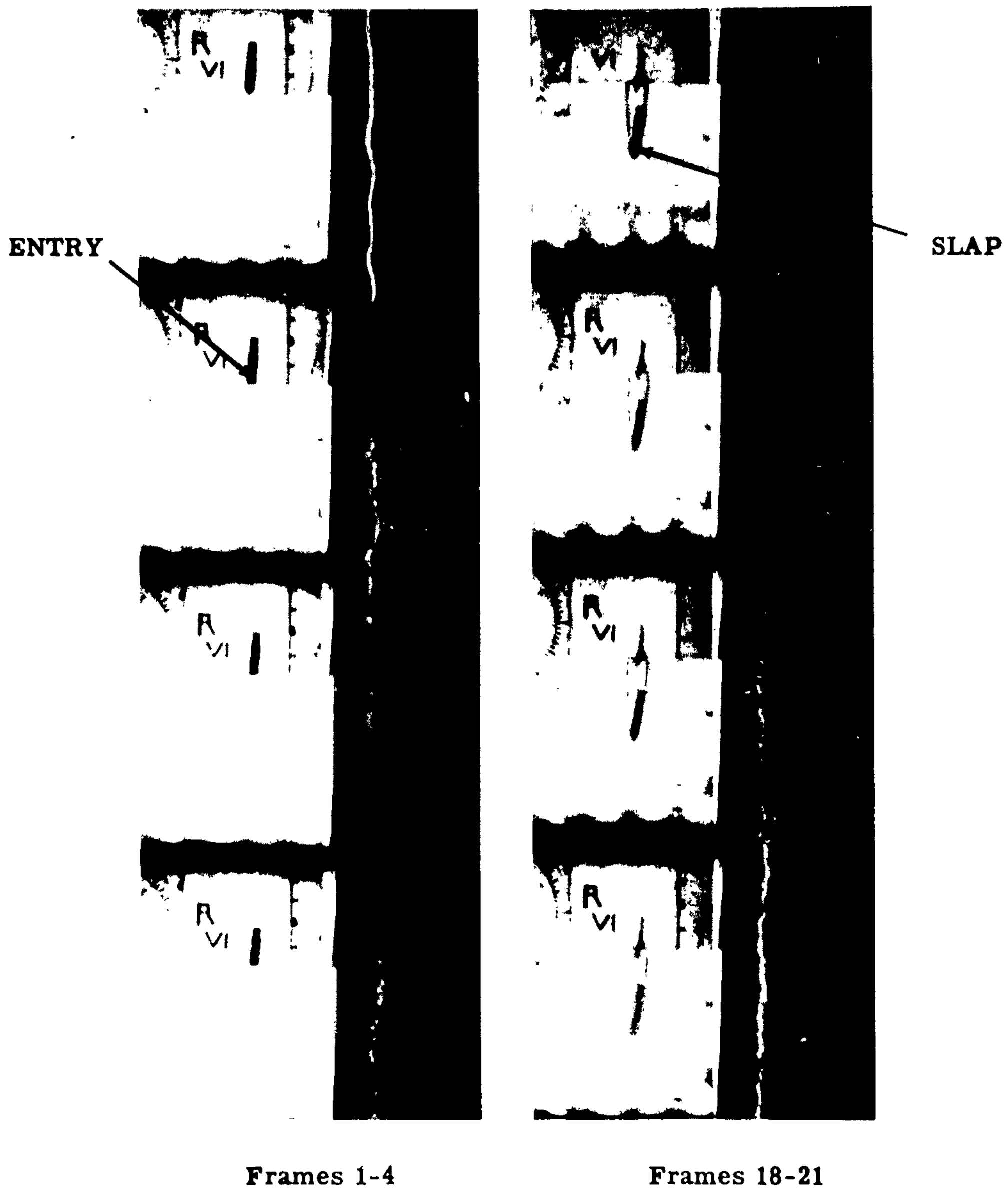
C - RIA Trajectory 11° from vertical

D - 500-cycle trace

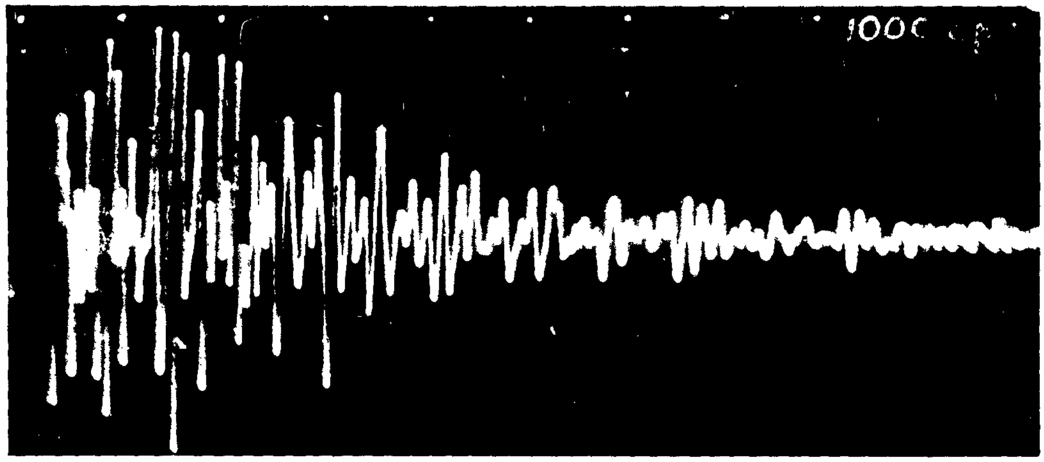


Frames 1-4 | Frames 9-12 | Frames 29-32

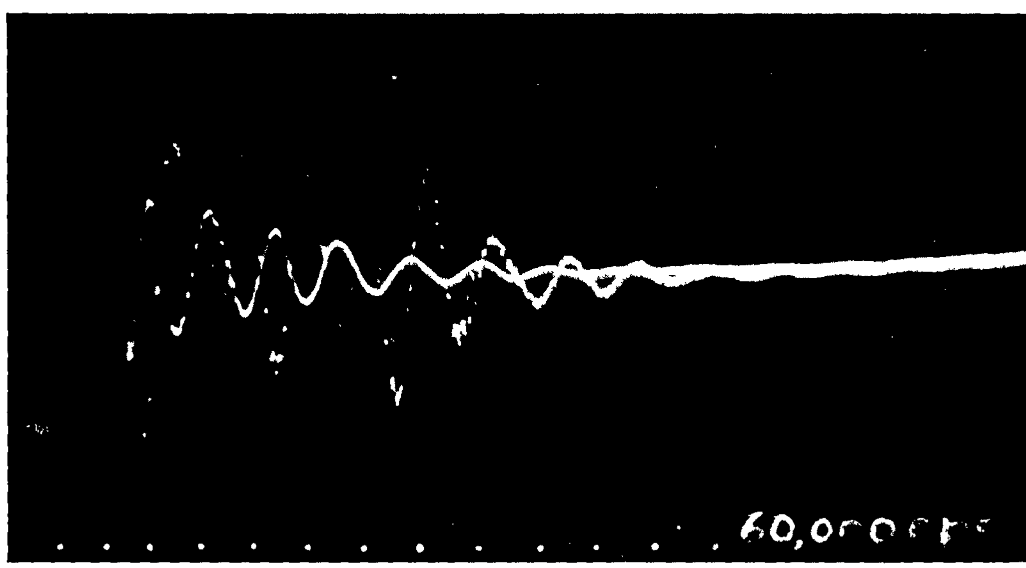
MARK 39



RIA (VERTICAL TRAJECTORY)



Signal obtained by tapping a full sized Mark 39 Mine Case with a hammer. Transducer mounted on side of case and blow struck on opposite side.



Signal obtained by tapping Mark 39 Model. Transducer mounted on side and blow struck on opposite side. Double trace resulted from two blows.

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